**SPACE WEATHERING EFFECTS ON APOLLO 17 BRECCIA 76015: REFLECTANCE SPECTROSCOPY AND MICROSTRUCTURE.** Lindsay P. Keller<sup>1</sup>, Susan J. Wentworth<sup>2</sup>, and David S. McKay<sup>3</sup>, <sup>1</sup>MVA, Inc. 5500 Oakbrook Parkway, Suite 200, Norcross, GA 30093 (E-mail: lkeller@mvainc.com). <sup>2</sup>C23, Lockheed-Martin, NASA-JSC Houston, TX 77058, and <sup>3</sup>SN, NASA-JSC, Houston, TX 77058.

Exposure to the space environment results in distinctive modifications to the chemical and physical characteristics of rock surfaces on the moon. These surface modifications on lunar rocks result in the formation of patina. Understanding the nature of patinas is important in the interpretation of remotely-sensed reflectance data from the moon and other airless bodies because of the potential for patinas to mask the underlying mineralogy. Our previous work on 76015 has shown that the presence of patina lowers the albedo relative to the substrate, imparts a slightly redder slope over the visible wavelengths, and attenuates the silicate absorption feature at ~1 µm [1]. In this study, we collected reflectance spectra from random spots on the patina surface in order to understand the spatial heterogeneity in the properties of the patina along with detailed analyses of the patina microstructure using electron microscopy to identify the materials responsible for the optical effects.

A 3 X 6-mm-sized fragment of patina from a surface of Apollo 17 breccia 76015,186 was analyzed using light microscopy, microspectrophotometry, scanning electron micoscopy, and transmission electron microscopy (TEM). Visible reflectance spectra were collected using a Zeiss MPM400 microscope photometer. Spectra were obtained from regions ~0.1 mm in diameter, over the wavelength range of 380-850 nm in 5 nm increments using darkfield techniques (illumination at an angle of 45° relative to the sample). Additional details of the reflectance measurements are given by [2]. For the TEM measurements, subfragments of the 76015 sample were embedded in epoxy, and thin sections (~50-70 nm thick) were cut with an ultramicrotome with the sample oriented so that cross sections of the patinasubstrate interface were obtained. The thin sections were analyzed using a JEOL 2010 TEM equipped with a Noran thin-window energy-dispersive x-ray (EDX) spectrometer. EDX data were quantified using the Cliff-Lorimer technique with experimental k-factors obtained from NIST-2063 thin film standard.

Numerous zap pits with glass-linings and spall zones are visible by light microscopy covering much of the chip of 76015. Between the zap pits, the surface is brownish in color and distinctly darker than the underlying material (mostly plagioclase and orthopyroxene). SEM images of the patina surface show mostly accretionary features such as glass splashes, attached mineral grains, and glass spheres, along with erosional features like fractures and abundant microcraters [3]. The surface shows considerable roughness at the  $\sim\!10~\mu m$  scale. Reflectance spectra of the patina were obtained from multiple regions  $\sim\!0.1~mm$  in diameter using a microscope photometer. Multiple reflectance spectra from randomly selected regions of the patina surface and from a fresh fracture surface of the substrate are collected in Fig-

ures 1 and 2. The brightest substrate spectra are from plagioclase-rich regions, the intermediate spectra ( $\sim$ 20-50% reflectance) are plagioclase-pyroxene mixtures, and the darkest spectra include a contribution from Fe-Ti oxides in addition to the silicates (Fig. 1). Many of the substrate spectra show the onset of the silicate absorption feature at 1  $\mu$ m. The spectra from the patina surface show a wide range in reflectance from  $\sim$ 5-55% at 550 nm, but most of the spectra have reflectivities that are typically <20%. The patina spectra are, on average, darker than the substrate spectra, exhibit flat to reddened slopes, and lack the pronounced absorption features observed in the substrate spectra.

A probable cause of reddening darkening in the reflectance spectra from the patina is the presence of submicroscopic Fe metal (SMFe) grains. Recent work has demonstrated that very fine SMFe (<10 nm) can generate a reddened slope and lower the albedo of materials, while coarser SMFe results in darkening without adding a red slope to the spectra [4]. Petrographic analyses using the TEM confirm that at least three components in the 76015 patina contain appreciable SMFe and are the major contributers to the optical properties of the patina: 1) vapor deposits, 2) accretionary melt/splash glass, and 3) in situ monomineralic melts. The outermost surface of the patina is covered by a partly amorphous coating ~50 nm thick of silica-rich glass with numerous inclusions of fine-grained (1 to 5 nm dia.) Fe metal grains. Quantitative EDX analyses of the rim material are given in Table 1. In regions, the Fe grains occur in distinct layers within the amorphous coating (i.e. the Fegrains are stratified). This amorphous coating is relatively uniform in composition and thickness over a distance of a few micrometers, and coats plagioclase, ilmenite, melt glass, and chromite. The amorphous coating represents material that was deposited on to the surface either by condensation of impact-derived vapors or by sputter deposition. Melt glass also contains abundant SMFe, but with larger grain sizes (up to 20-40 nm in dia.). Typical melt glasses have compositions that resemble the bulk composition of the rock and nearby soils (Table 2). Finally, we have observed regions of partial melting of ilmenite and chromite.

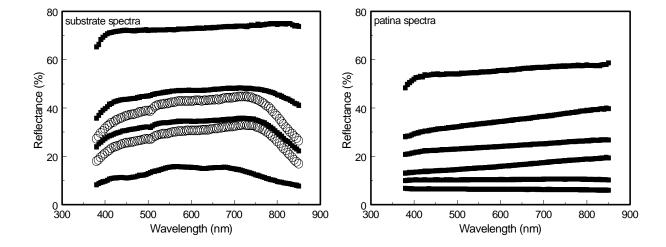
**References**. [1] Keller, L. P. *et al.*, 1996, *LPSC* 27, 661. [2] Bradley, J. P. *et al.*, 1996, MPS 31, 394, [3] Wentworth, S. J. *et al.*, 1996, *LPSC* 27, 1423, [4] Allen, C. C. *et al.*, 1996, *LPSC* 27, 15.

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Figure 1. Visible reflectance spectra from the fresh substrate surface of 76015. The observed upper and lower extremes along with intermediate spectra are plotted.

Figure 2. Visible reflectance spectra from patina on 76015. As with the substrate data, the upper and lower range in spectra are plotted as well as intermediate spectra.



TABL									
	material								
#	0	Mg	Al	Si	Ca	Ti	Cr	Fe	Substrate
26	56.0	5.26	10.60	19.3	5.05	0.21	0.0	3.58	glass
32	50.2	4.43	4.44	28.0	2.35	0.54	1.0	9.04	chromite
5	59.7	2.55	6.58	24.9	2.14	0.15	0.0	3.98	plagioclase
8	59.4	6.23	8.64	18.4	2.32	0.19	0.0	4.82	plagioclase
13	61.2	2.90	5.56	22.9	1.95	0.44	0.0	5.05	plagioclase
16	61.9	1.24	12.64	19.2	4.21	0.00	0.0	0.81	plagioclase
18	60.9	1.78	6.16	26.9	1.83	0.29	0.0	2.14	plagioclase
20	61.3	2.35	2.98	28.8	0.85	0.35	0.0	3.37	ilmenite
116	61.6	1.96	3.59	19.7	1.48	1.63	0.0	10.06	glass
24	57.0	3.65	9.15	22.7	3.12	0.24	0.0	4.14	plagioclase

TABLE 2. Quantitative TEM-EDX analyses (at.%) of melt glass									
	within the	e patina c	n fragme						
#	0	Mg	Al	Si	Ca	Ti	Cr	Fe	
103	61.2	3.7	11.45	16.2	5.8	0.4	0	1.25	
104	60.3	7.68	7.35	16.0	4.28	0.83	0	3.56	
106	60.1	5.21	4.9	16.5	4.74	1.32	0	7.25	
108	60.4	6.28	6.9	17.0	4.61	0.42	0	4.39	